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Relationship between extreme temperature and electricity demand in Pakistan

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Abstract

Nowadays, different sectors of the economy are being significantly affected by the weather vagaries. Electricity market is one of the most sensitive sectors, due to the fact that electricity demand is connected to the numerous climatic variables, especially the atmospheric temperature. In this paper we have deduced the link between electricity consumption and mean monthly maximum temperature index in Pakistan, as a case study. ARIMA time series forecast model is developed for the temperature index. The forecast values of mean monthly maximum temperature shows an increasing trend. Linear trend model for electricity consumption is also developed as a function of temperature. Electricity consumption reveals a significant trend due to increase in temperature and socio- economic factors. The monthly behavior of our forecast values depicts that the electricity consumption is more for summer season, and this demand will be highest (6785.6 GWh) in July 2020, due to rise in temperature. Forecast model reveals that the electricity consumption (EC) and mean monthly maximum temperature are increasing with the passage of time.

Keywords: Maximum temperature index; Electricity consumption; Time series modeling; Forecast model

Background

It is well-known that electricity plays a critical role in economic growth, technological development and planning of a country. A study report of World Bank [1], states that no country in the world has succeeded in financial system, without using contemporary technology to produce energy [2]. Smith and Tirpak [3], showed the possible effects of climate change on the USA, across a range of sectors including electricity and that for Colombo by Andrew [4]. Many researchers estimated the impact of global warming on the energy expenditures in a region by Rosenthal [5]. Numerous economical activities have presented climatic changes, so that the predictable revenues may be seriously affected by extreme weather events. Extreme weather events are the infrequent or rare conditions of weather intensity in a locality, like heat waves, cold waves, tropical cyclone, flood, thunderstorm etc. The power sector is one of the most vulnerable to extreme weather, predominantly electricity consumption. Since electricity cannot be stored so the produced electricity must immediately be consumed, this implies that an appropriate model is needed to forecast future electricity demand by Valor [6].

In developin'g countries, there is a powerful positive correlation among wealth and energy especially electricity utilization. Though, the method of electricity production and consumption may generate air pollution and greenhouse gas which results global warming (Lee and Chiu [2], Ferguson [7]). Earlier studies mostly apply time-series or cross-sectional datasets to examine the appropriate topic of energy (Wolde-Rufael, [8,9]). Investigators have also started to utilize panel data to investigate the issues on energy (Lee and Lee [10]). Economic derivatives, such as future and alternative agreement on electricity, are usually engaged with this objective [11]. As electricity has become the basic need for survival in Pakistan. Unfortunately our country has been in deficit regarding electricity. Only 16% of rural population have grid-connected electricity, compared with 85% of the urban population [12]. The government called 2nd National Energy Conference on 9th April, 2012 and discussed critical issues and compelled to decide two holidays a week to recover the energy crises. Now it has become a big challenge for new government in Pakistan. Prime minister calls energy

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conference immediately, after taking over his responsibility. To overcome these problems an appropriate analysis of the link between electricity consumption and climatic variables, particularly air temperature, must be undertaken. The current work is an attempt to study the above relationship in Pakistan.

This communication is planned as, "Data description and methodology" gives an account of the data used in the study, and "Test for stationarity of temperature series" gives the estimates of the constancy test for temperature data. The time series model of temperature is constructed in "Time series modeling", while "Results and discussion" shows the forecast values of EC using regression technique. Finally, "Conclusion" summarizes the conclusions drawn from this investigation.

Data description and methodology

Electricity consumption in Pakistan

Currently Pakistan is facing severe energy crisis and power failures. The trend of power shortages has increased about 5000 MW, load shedding has been increased from 8 to 14 hours daily. Industrial growth has been decelerated and ultimately the whole economy has crashed down [13], so investigation of electricity consumption is an important study. A series of monthly electricity consumption (EC) of Pakistan in GWh, across the period from January 1990 through December 2010, has been used in this study. The data was recorded by Department of Federal Bureau of Statistics Pakistan. This data consists of electricity consumption in all economic sectors such as industrial, housing, and commercial sectors of Pakistan, because regional or sector wise disaggregated data was not available. Figure 1 shows that electricity demand has a considerable, growing trend that can be associated to demographic, community, and economic aspect, while a gradual increment in maximum temperature has also been observed.

The series of electricity demand shows seasonal effect, that can be examined with the monthly seasonal variation index (MSVI) and can be defined as;

$$\mathbf{MSVI}_{ij} = \frac{\mathbf{MEC}_{ij}}{\mathbf{MAE}_j} \tag{1}$$

where MSVI_{ij} is the index value for month i in year j, MEC_{ij} is the monthly electricity consumption for month i in year j, and MAE_j is the monthly average electricity load for year j [6]. Figure 2 illustrate the average, maximum, and minimum MSVI values for each month of the year. Here the average values confirm the relative behavior of electricity consumption between different months while the variation between the highest and lowest amount shows the actual deviation from this mean behavior.

The monthly seasonality graph demonstrates that the electricity demand starts to rise up from March to August owing to increased use of air conditioning systems and is maximum in months of July and August while minimum in January and February. This gives graphical support for our assumption that electricity consumption increases with maximum temperature in our country

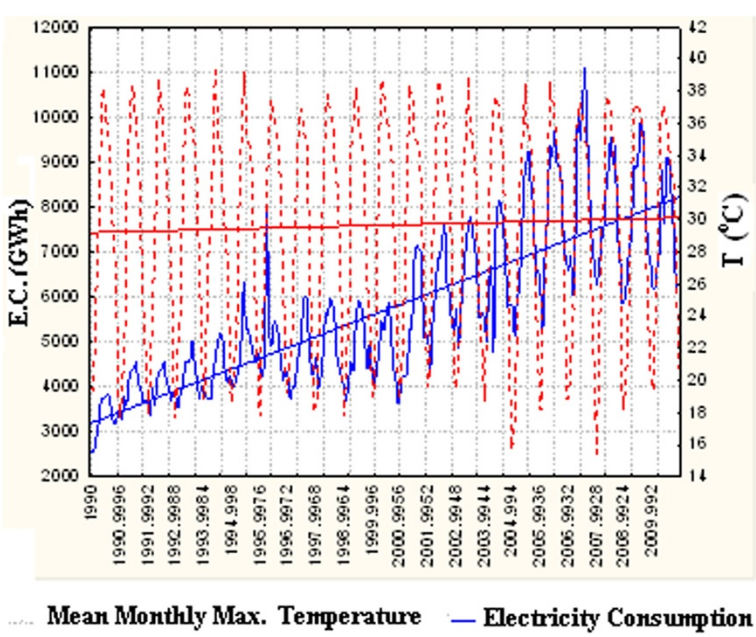

Figure 1 Relationship b/w electricity demand and maximum temperature from 1990 to 2010.

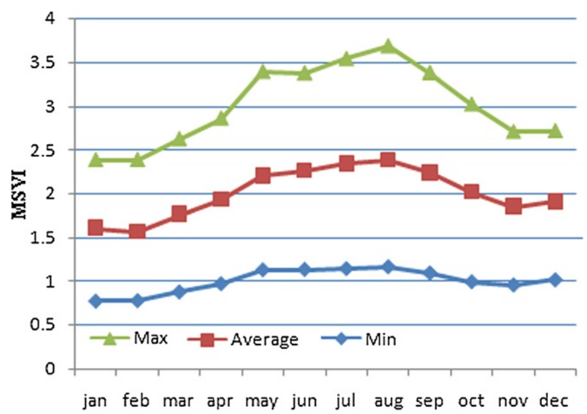

Figure 2 Monthly seasonal behavior of electricity consumption from 1990 through 2010.

while it has less correlation with minimum temperature also. Unfortunately the daily data for electricity consumption was not available due to which we are unable to say anything about the daily profile of electricity consumption e.g. in working days and holidays.

The weather variable

The results of past case studies reveal that the air temperature is the most important weather variable having an effect on electricity demand, while other variables i.e. humidity, wind, speed etc may also have an effect on temperature [6,14-17]. Since our country lies between latitudes 24°N to 36°N and longitudes 62°E to 78°E, so the maximum temperature affects electricity consumption a lot as compare to min temperature. Due to which we have estimated only the impact of maximum temperature on electricity consumption in this study. To show the average maximum temperature of Pakistan, we have taken the records of mean monthly maximum temperature of 18 meteorological stations (Chitral, Peshawar, Parachinar, Murree, Mianwali, Faisalabad, Lahore, Multan, Khanpur, Zhob, Queta, Khuzdar, Nokundi, Punjgur, Jiwani, Rohri, Nawabshah, Karachi and Badin) for the period from 1990 to 2010 which are spatially distributed throughout the country.

Since the accessible electricity consumption data are not present regionally, so a population weighted temperature index TI (°C) has been estimated from the mean monthly maximum temperatures of eighteen weather stations spatially spread across the country. The reason of selecting populations as weighting aspect is that weather affects the electricity consumption practices through the response of people to weather. i.e. depending on the heat, or coldness, people will increase or decrease the use of electric heating tools or air conditioners. Thus the higher the population has the higher the influence of climatic situation in electricity demand [6].

Test for stationarity of temperature series

Since we are using time series data so for the purpose of time series modeling first we have to check the stationarity of the data. A stochastic (or time-series) is called stationary if its mean and variance are constant over time. In addition, the value of the co-variance between the two time periods depends only on the lag between the two time periods and not the actual time at which the covariance is estimated. Although there are several tests of constancy, but we discuss only those that are prominently used in the literature i.e. Unit Root Test.

Unit root stochastic process

Consider a random walk model

$$Y_t = \rho Y_{t-1} + u_t \quad -1 \leq \rho \leq 1 \tag{2}$$

This model resembles the Markov first-order autoregressive model and depends upon the value of “ρ”. if ρ = 1 then the above model shows nonstationarity or has unit root, where u_t is white noise error term.

Unit root test

This test starts from above equation and we simply regress Y_t on its (single period) lagged value Y_{t-1} and estimated if the predictable value of ρ is statistically identical to 1 then the series has unit root and we reject the null hypothesis.

For theoretical reasons, we manipulate eq. (2) as follows: subtract Yt -1 from both sides of eq. (2) we have

$$\begin{aligned} Y_t - Y_{t\text{-}1} &= \rho Y_{t-1} - Y_{t-1} + u_t \\ Y_t - Y_{t-1} &= Y_{t-1}(\rho - 1) + u_t \\ \Delta Y_t &= \delta Y_{t-1} + u_t \end{aligned} \tag{3}$$

where δ = (ρ − 1) and Δ is the first difference operator. Further, we estimate eq. (3) instead of eq. (2) and test (null) hypothesis that δ = 0. If δ = 0, then ρ = 1, which is the condition of unit root, implies that the time series under study is not stationary.

The Augmented Deckey Fuller (ADF) test

To tackle the autocorrelation problem, a test developed called Augmented Deckey Fuller (ADF) test. Now the test is conducted by “augmenting” the following three equations by adding the lagged values of the dependent variable Δ Yt

Y_t is a random walk with;

Intercept only i.e. β_1 is $$\Delta Y_t = \beta_1 + \delta Y_{t-1} + u_t \quad (4)$$

Trend and intercept i.e $\beta_2 t$ & β_1. $$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + u_t \quad (5)$$

No trend and no intercept. $$\Delta Y_t = \delta Y_{t-1} + u_t \quad (6)$$

Hypotheses

Null Hypotheses Ho: Variable has unit root (data is non stationary)

Here we can reject the null hypotheses in two ways:

i) If p-value is less than 5%
ii) If absolute value of Augmented Deckey Fuller test statistics is greater than the critical value at 1% and 5% significance level.

According to ADF test, the temperature series show no constancy in level forms because both the above conditions are not satisfied. Since temperature is not in stationary form so we will take first difference to make it stationary for time series modeling.

Now from Table 1,2 and 3 [18] the p-values are less than 5% and the absolute value of ADF test statistics is greater than the critical values at 1%, 5% and 10% level of significance also. So the first difference of temperature time series is stationary.

Time series modeling

Several researchers used AR(1) model to show daily maximum temperature fluctuations. Using a statistical package, E-VIEWS ver. 14, the parameter values for different orders of autoregressive (AR), moving average (MA) & auto regressive integrated moving average (ARIMA) models e.g. AR(1), AR(2), MA(1), MA(2), ARIMA(1,1,1), ARIMA (1,1,2), ARIMA(1,1,5), ARIMA(3,1,1), ARIMA(4,1,1) and ARIMA(4,1,4) were estimated. Now, in order to get optimized model, we use Akaike Information Criteria (AIC), which aims to optimize the exchange between goodness of fit and model parsimony. AIC can be represented mathematically as;

$$\mathbf{AIC} = \ln\left(\sigma^2\right) + \frac{2(p+q+1)}{n} \quad (7)$$

where n implies the sample size of the series and σ^2 is the mean squared error of the ARIMA model fit to the series. p is the order of AR parameter while q is the order of MA parameter [4]. Thus for ARIMA (4,1,4) model, p = 4, q = 4 and 1 shows the first difference. Here, our objective is to minimize AIC so that the required model can best explain fluctuating behavior of process under study.

For temperature data series the AIC shows that the ARIMA (4,1,4) is the best fitted model. The equation of this model is;

$$T_{\mathrm{cal.}} = \mathbf{0.00011} + \mathbf{2.571}T_{\mathbf{t-1}} - \mathbf{3.16}T_{\mathbf{t-2}} + \mathbf{2.063}T_{\mathbf{t-3}} - \mathbf{0.707}T_{\mathbf{t-4}} + 3.026U_{\mathbf{t-1}} - \mathbf{3.55}U_{\mathbf{t-2}} + \mathbf{1.835}U_{\mathbf{t-3}} - \mathbf{0.313}U_{\mathbf{t-4}} \quad (8)$$

where T_{cal} Indicates the forecast values of temperature while T and U with subscript t show the time lagged values of autoregressive and moving average respectively. Table 4 gives the estimated future values of the monthly mean maximum temperature of Pakistan from Jan 2011 to December 2020 using above model (Eq. 8).

Table 1 First difference for Intercept form

Null hypothesis: D(Y) has a unit root			
Exogenous: constant			
Lag Length: 10 (Automatic based on SIC, MAXLAG=15)			
		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		−16.78416	0.0000
Test critical values:	1% level	−3.457515	
	5% level	−2.873390	
	10% level	−2.573160	

Table 2 First difference for Trend and intercept form

Null hypothesis: D(Y) has a unit root			
Exogenous: constant, linear trend			
Lag length: 10 (Automatic based on SIC, MAXLAG=15)			
		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		−16.74452	0.0000
Test critical values:	1% level	−3.996754	
	5% level	−3.428660	
	10% level	−3.137757	

Table 3 First difference for No Trend No Intercept form

Null hypothesis: D(Y) has a unit root			
Exogenous: none			
Lag length: 10 (Automatic based on SIC, MAXLAG=15)			
		t-Statistic	Prob.
Augmented Dickey-Fuller test statistic		−16.81727	0.0000
Test critical values:	1% level	−2.574633	
	5% level	−1.942153	
	10% level	−1.615818	

Table 4 Forecast values of mean monthly maximum temperature series for Pakistan from Jan, 2011 to Dec, 2020

	Mean monthly maximum temperature (°C)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
2011	20.81	22.15	25.32	29.85	34.72	38.39	39.38	37.24	32.90	28.01	24.00	21.60	21.60
2012	21.03	22.31	25.35	29.81	34.73	38.50	39.50	37.27	32.83	27.94	23.98	21.64	21.64
2013	21.10	22.39	25.43	29.90	34.81	38.56	39.52	37.25	32.79	27.91	23.98	21.67	21.67
2014	21.15	22.46	25.53	29.99	34.90	38.61	39.53	37.22	32.75	27.88	23.98	21.69	21.69
2015	21.20	22.54	25.62	30.10	34.99	38.67	39.54	37.19	32.72	27.86	23.98	21.72	21.72
2016	21.26	22.61	25.71	30.20	35.08	38.72	39.54	37.17	32.68	27.84	23.98	21.74	21.74
2017	21.31	22.68	25.81	30.30	35.17	38.77	39.55	37.14	32.65	27.82	23.98	21.77	21.77
2018	21.36	22.76	25.90	30.40	35.25	38.82	39.56	37.11	32.61	27.80	23.98	21.80	21.80
2019	21.41	22.83	25.99	30.50	35.34	38.87	39.56	37.08	32.58	27.78	23.99	21.82	21.82
2020	21.46	22.91	26.09	30.60	35.43	38.92	39.57	37.06	32.55	27.76	23.99	21.85	21.85
Average	21.21	22.56	25.67	30.16	35.04	38.68	39.53	37.17	32.71	27.86	23.98	21.73	

Results and discussion

Extreme temperature events affect electricity demands primarily by raising the number of air conditioner used, as people attempt to sustain a predictable level of comfort. Consequently, increase in extreme temperature events, results an increase in air conditioner use and power demand as well. Power utilities might have to approve new approach to fulfill the increased loads [4]. In addition the more demands can also sag the transmission lines with hot temperature.

Now, we will justify our hypothesis by using exploratory data analysis (EDA) for both electricity and temperature data series. EDA makes a general use of robust statistics and relies greatly on graphical techniques, which present an idea about the shape of the distribution of data under study. It also gives a widespread description of the underlying system in the form of models. To assess that how peak power demand strength to vary, it has to be correlated with maximum temperature. As, a correlation is made the probability of identical or exceeding certain electricity demand thresholds can be determined [4].

Figure 3 depicts a positive correlation between electricity consumption (EC) and temperature index (TI). The Pearson correlation of E.C. and TI is 0.412 with p-value (0.000) less than 5% and T statistics is 7.15. The correlation value is not very high because the electricity demand is always greater than its production in Pakistan. So the electricity production authorities are compelled to initiate load shedding to manage this problem, due to which exact correlation could not be found. Secondly, we could not collect the daily data and sector wise disaggregated data of EC in our country to show its exact relationship with temperature. Coefficient of determination is highest for the linear model as compared to quadratic and nonlinear models. This shows that a linear model

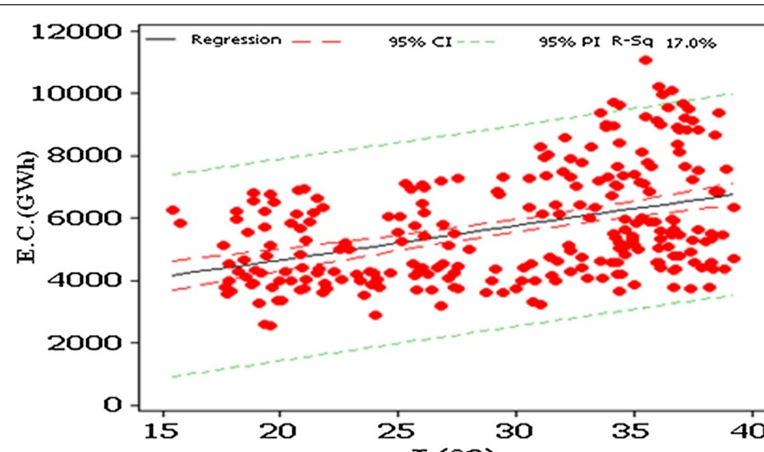

Figure 3 Correlation between EC and TI with best fitted regression line.

Table 5 Monthly forecast values of electricity consumption from Jan, 2011 to Dec, 2020 for Pakistan

Year	Electricity consumption (GWh)												Yearly average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2011	4735.9	4881.7	5228.6	5724.1	6256.3	6656.5	6765.1	6531.6	6056.5	5522.4	5084.5	4822.3	**5688.8**
2012	4759.7	4898.9	5231.8	5719.5	6257.4	6668.7	6778.4	6534.2	6049.4	5514.6	5082.3	4826.2	**5693.4**
2013	4767.4	4908.1	5241.0	5728.6	6266.1	6675.4	6780.8	6532.0	6045.1	5511.4	5082.0	4829.1	**5697.2**
2014	4773.2	4916.2	5251.0	5739.4	6275.7	6681.3	6781.8	6529.1	6041.1	5508.8	5082.0	4831.9	**5701.0**
2015	4778.7	4924.3	5261.2	5750.4	6285.4	6687.1	6782.5	6526.2	6037.2	5506.3	5082.0	4834.8	**5704.7**
2016	4784.2	4932.3	5271.3	5761.5	6295.0	6692.8	6783.3	6523.2	6033.4	5503.9	5082.1	4837.6	**5708.4**
2017	4789.8	4940.4	5281.5	5772.5	6304.6	6698.5	6783.9	6520.3	6029.5	5501.5	5082.3	4840.5	**5712.1**
2018	4795.4	4948.6	5291.7	5783.5	6314.1	6704.0	6784.5	6517.3	6025.7	5499.2	5082.5	4843.5	**5715.8**
2019	4801.0	4956.7	5302.0	5794.5	6323.7	6709.5	6785.1	6514.3	6022.0	5496.9	5082.7	4846.5	**5719.6**
2020	4806.7	4965.0	5312.2	5805.6	6333.1	6715.0	6785.6	6511.3	6018.2	5494.6	5083.0	4849.5	**5723.3**
Monthly average	**4779.2**	**4927.2**	**5267.2**	**5758.0**	**6291.1**	**6688.9**	**6781.1**	**6524.0**	**6035.8**	**5506.0**	**5082.5**	**4836.2**	

can better predict the values of E.C. in future. Figure 3 also reveals that when temperature increases above 30°C, the EC rapidly increases due to cooling appliances. The prediction equation for EC can be shown by following equation.

$$\mathbf{E.C.(T) = 2461 + 109.3T(^\circ C)} \tag{9}$$

where T is the mean monthly maximum temperature and EC is the electricity consumption in Pakistan. Now being the best fitted model eq. (9), peak power demand corresponding to threshold temperatures has been computed and shown in Table 5. Since the correlation between electricity demand and mean monthly maximum temperature is not so good, implies that there are many other factors which are also accountable to increase the electricity consumption e.g. population, inflation rate of heating appliances, unit price of electricity, etc. In this article we have only attempted to calculate the expected change in EC, due to the increase of mean monthly maximum temperature for Pakistan by using the above forecast values of temperature from January 2011 to December 2020 (Table 4).

Now we use Figure 4 to compare the average monthly behavior of EC and maximum temperature for the predicted values in future. This figure also throws light on the correlation between these two parameters keeping influence of other parameters constant. This indicates that the EC is maximum for summer season and minimum for winter season. The cyclic trend in temperature is similar as that of EC, so one cannot neglect the influence of maximum temperature on electricity consumption.

Conclusion

This study demonstrates that the the electricity consumption (EC) increases with mean monthly maximum temperature having significant correlation coefficient 0.412. This correlation is not so good due to the insufficient electricity production in our country, the authorities are compelled to get load shedding and we could not get the monthly load shedding hour's data. The peak power demand is significantly increased during summer season as compared to winter season due to the uses of cooling appliances. The monthly behavior depicts that EC is more for summer season and highest demand will be 6785.6 (GWh) in July, 2020 due to increase in temperature. The average monthly behavior of forecast

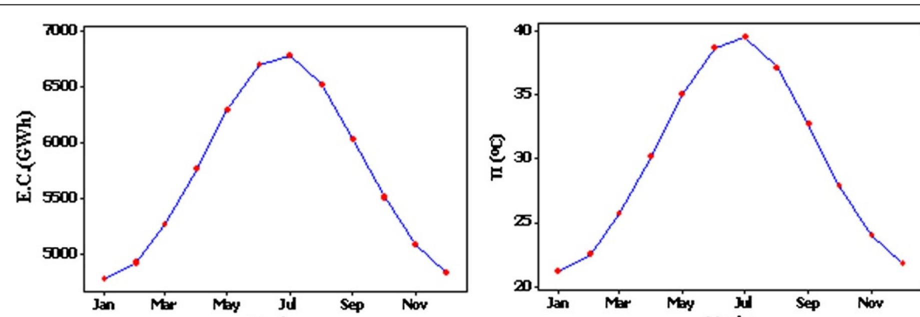

Figure 4 Monthly average forecast values of temperature (°C) & Electricity consumption (GWh) from 2011 to 2020.

values of temperature and electricity has been shown in Figure 4, which reveals that the maximum temperature has a great influence on EC keeping other parameters constant. The current study also suggests that ARIMA (4,1,4) model is the best fitted model for the future prediction of temperature series. Our calculation also shows that for an increase of 1°C temperature there will be an increase of 109.3 million-kWh electricity demand for Pakistan. So the power utilities have to adopt new strategies in order to meet future electricity demands.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
JI has given the techniques and ideas of the paper. He also removed technical as well as grammatical mistakes from the paper. MS helped me to analyze the data from statistical software. MA (corresponding author) has got data from Pak. Met dept. And Federal Bureau of statistics, analyzed the data, got forecast values of EC, handled all the comments from reviewer side and compiled the paper by getting suggestions from coauthors. All authors read and approved the final manuscript.

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